

APPLICATION

FOR UNITED STATES LETTERS PATENT

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, **Charles L. Tilton**, a citizen of the United States, **Tahir Cader**, a citizen of the United States, and **Nathan G. Muoio**, a citizen of the United States, have invented a new and useful dynamic thermal management spray system of which the following is a specification:

1
2 **Dynamic Thermal Management Spray System**

3
4 **CROSS REFERENCE TO RELATED APPLICATIONS**

5
6 I hereby claim benefit under Title 35, United States Code, Section 120 of
7 United States patent application Serial Number 10/243,683 filed September 13, 2002
8 which is subject to a restriction requirement. This application is a divisional of the
9 10/243,683 application. The 10/243,683 application is currently pending. The
10 10/243,683 application is hereby incorporated by reference into this application. Two
11 additional divisional applications from the above-stated application have been filed
12 relating to this application identified by U.S. Serial Nos. 10/723,608 and Serial No.
13 10/723,607.
14
15

16 **STATEMENT REGARDING FEDERALLY**
17 **SPONSORED RESEARCH OR DEVELOPMENT**

18 Not applicable to this application.
19
20

21 **BACKGROUND OF THE INVENTION**

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23
24
25 **Field of the Invention**

26
27 The present invention relates generally to electronic device burn-in systems and
28 more specifically it relates to a dynamic thermal management spray system for
29 efficiently thermally managing one or more electronic devices.

Description of the Related Art

Thermal management systems for electronic device burn-in equipment have been in use for years. Conventional thermal management systems utilized today are comprised of, for example, either air-cooled enclosures, or fluid-cooled cold plates. Upcoming technologies include refrigeration systems or other two-phase based technologies.

When producing electronic devices, manufacturers typically perform three different tests on the electronic devices prior to shipping: (1) sort, (2) burn-in, and (3) class testing. Sort test requires maintaining the wafers at a modest temperature, e.g. 35° Celsius, while the wafers are probed for defects. Conventional fluid-cooled cold plates are employed at this stage. Projected heat fluxes, even at the wafer sort, are pointing to the fact that a more effective thermal management technology is needed at this stage.

Burn-in of the electronic devices is typically accomplished utilizing elevated voltages and temperatures in a process that raises the junction temperatures of a batch of electronic devices. The lifespan of an electronic device is closely related to its operating temperature wherein operating under increased temperatures reduces the effective lifespan of the electronic device. By applying increased voltages and temperatures to an electronic device, the weaker electronic devices will fail during testing. The length of the burn-in of electronic devices is directly tied to the median junction temperature of the batch of electronic devices. It is therefore important to maintain a relatively narrow junction temperature spread that provides a higher median temperature. For example, a poor thermal management system can produce a junction temperature spread from 75° to 125° Celsius resulting in a low median junction

1 temperature, longer burn-in time and higher associated burn-in costs. Modern fluid-
2 based thermal management systems are currently able to lower the junction
3 temperature spread to approximately 95° to 110° Celsius thereby reducing burn-in time
4 and burn-in costs.

5
6 Class test is the final step in the testing process and is comprised of a final
7 series of tests to validate functionality and quantify speeds. During class test, non-
8 uniform heating of the electronic devices typically occurs. A electronic device's speed
9 is typically derated by 0.15% for every degree Celsius rise above the target temperature
10 (junction temperature, T_j). It is therefore important to maintain the temperature of the
11 electronic devices relatively close to the target temperature (T_j).

12
13 Due to increasing chip heat fluxes (projected to exceed 125 W/cm² by the year
14 2004), conventional thermal management systems for electronic device burn-in are
15 reaching their cooling limits. A further problem with conventional thermal
16 management systems is that they are inefficient, complex, costly to implement and
17 costly to operate. A further problem with conventional thermal management systems
18 is that the resulting junction temperature spreads result in relatively long burn-in times
19 of the electronic device devices. Another problem with conventional thermal
20 management systems is that they require significant amounts of power to operate.

21
22 While these devices may be suitable for the particular purpose to which they
23 address, they are not as suitable for efficiently thermally managing one or more
24 electronic devices. Conventional dynamic thermal management spray systems are
25 inaccurate and inefficient thereby increasing the testing costs for an electronic device
26 manufacturer.

27
28 In these respects, the dynamic thermal management spray system according to
29 the present invention substantially departs from the conventional concepts and designs

1 of the prior art, and in so doing provides an apparatus primarily developed for the
2 purpose of efficiently thermally managing one or more electronic devices.

1

2 **BRIEF SUMMARY OF THE INVENTION**

3

4 In view of the foregoing disadvantages inherent in the known types of
5 electronic device burn-in systems now present in the prior art, the present invention
6 provides a new dynamic thermal management spray system construction wherein the
7 same can be utilized for efficiently thermally managing one or more electronic devices.
8

9 The general purpose of the present invention, which will be described
10 subsequently in greater detail, is to provide a new dynamic thermal management spray
11 system that has many of the advantages of the electronic device burn-in systems
12 mentioned heretofore and many novel features that result in a new dynamic thermal
13 management spray system which is not anticipated, rendered obvious, suggested, or
14 even implied by any of the prior art electronic device burn-in systems, either alone or
15 in any combination thereof.
16

17 To attain this, the present invention generally comprises one or more spray
18 units having an adjustable spray characteristic. The spray characteristic of at least one
19 spray unit is adjusted based upon the desired thermal management of one or more
20 electronic devices. Adjusting the spray characteristic is preferably comprised of
21 increasing/decreasing the fluid flow rate.
22

23 There has thus been outlined, rather broadly, the more important features of the
24 invention in order that the detailed description thereof may be better understood and in
25 order that the present contribution to the art may be better appreciated. There are
26 additional features of the invention that will be described hereinafter and that will form
27 the subject matter of the claims appended hereto.
28

29 In this respect, before explaining at least one embodiment of the invention in

1 detail, it is to be understood that the invention is not limited in its application to the
2 details of construction and to the arrangements of the components set forth in the
3 following description or illustrated in the drawings. The invention is capable of other
4 embodiments and of being practiced and carried out in various ways. Also, it is to be
5 understood that the phraseology and terminology employed herein are for the purpose
6 of the description and should not be regarded as limiting.

7
8 A primary object of the present invention is to provide a dynamic thermal
9 management spray system that will overcome the shortcomings of the prior art devices.

10
11 A second object is to provide a dynamic thermal management spray system that
12 efficiently thermally manages one or more electronic devices.

13
14 Another object is to provide a dynamic thermal management spray system that
15 thermally manages one or more electronic devices by adjusting the fluid flow rate
16 sprayed upon the electronic devices.

17
18 Another object is to provide a dynamic thermal management spray system that
19 minimizes junction temperature spread during electronic device testing procedures.

20
21 An additional object is to provide a dynamic thermal management spray system
22 that is energy efficient, flexible and relatively small in size.

23
24 Another object is to provide a dynamic thermal management spray system that
25 is capable of cooling a variety of electronic device devices using the same burn-in
26 equipment.

1 An additional object is to provide a dynamic thermal management spray system
2 that transfers heat from an electronic device using conduction, convection, phase
3 change or a combination thereof.
4

5 Another object is to provide a dynamic thermal management spray system that
6 works with existing and various types of burn-in and thermal management equipment
7 currently utilized in the industry.
8

9 Another object is to provide a dynamic thermal management spray system that
10 is capable of managing the temperature of electronic devices that utilize an integrated
11 heat sink and electronic devices that do not utilize an integrated heat sink.
12

13 A further object is to provide a dynamic thermal management spray system that
14 is capable of thermally managing one or more electronic devices of various shapes,
15 sizes and structures.
16

17 Other objects and advantages of the present invention will become obvious to the
18 reader and it is intended that these objects and advantages are within the scope of the
19 present invention.
20

21 To the accomplishment of the above and related objects, this invention may be
22 embodied in the form illustrated in the accompanying drawings, attention being called
23 to the fact, however, that the drawings are illustrative only, and that changes may be
24 made in the specific construction illustrated and described within the scope of the
25 appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Various other objects, features and attendant advantages of the present invention will become fully appreciated as the same becomes better understood when considered in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the several views, and wherein:

FIG. 1 is a schematic diagram illustrating the overall structure of the present invention.

FIG. 2 is a block diagram illustrating the communication connections between the control unit and the related components of the present invention.

FIG. 3 is a flowchart illustrating the overall operation of the present invention.

FIG. 4 is an upper perspective view of an exemplary spray enclosure with a burn-in board positioned within.

FIG. 5 is an upper perspective view of the exemplary spray enclosure with the burn-in board removed illustrating the spray assembly within the spray enclosure.

FIG. 6 is a cross sectional view taken along line 6-6 of Figure 5 illustrating the spray assembly within the exemplary spray enclosure.

FIG. 7 is an upper perspective view of the upper portion of the spray assembly.

FIG. 8 is an upper perspective view of the lower portion of the spray assembly.

1
2 FIG. 9 is an upper perspective view of an exemplary burn-board.

3
4 FIG. 10 is an upper perspective view of a spray assembly.

5
6 FIG. 11 is an exploded upper perspective view of the spray assembly.

7
8 FIG. 12 is a top view of the spray assembly.

9
10 FIG. 13 is an upper perspective view of the spray assembly inverted with the
11 rear plate removed.

12
13 FIG. 14 is a bottom view of the spray assembly with the rear plate removed.

14
15 FIG. 15 is a side view of the spray assembly illustrating the movement of the
16 second portion within the first portion.

17
18 FIG. 16 is a side cutaway view of the spray assembly dispensing fluid upwardly
19 upon the electronic device having a higher profile (e.g. containing an integrated heat
20 sink) within a socket of the burn-in board.

21
22 FIG. 17 is a side cutaway view of the spray assembly dispensing fluid upwardly
23 upon the electronic device having a lower profile (e.g. no integrated heat sink) within a
24 socket of the burn-in board with the second portion fully extended from the first
25 portion.

26
27 FIG. 18 is a side cutaway view of a dynamic spray control for the spray units.

DETAILED DESCRIPTION OF THE INVENTION

A. Overview

Turning now descriptively to the drawings, in which similar reference characters denote similar elements throughout the several views, FIGS. 1 through 18 illustrate a dynamic thermal management spray system 10, which comprises a reservoir 80 for storing a volume of fluid, a main pump 82 fluidly connected to the reservoir 80, and a plurality of spray units 40 fluidly connected to the main pump 82. The spray units 40 dispense the fluid upon the surface of the electronic device 18 during burn-in or thermal management thereby maintaining a relatively constant temperature. In the present embodiment of the invention, each of the spray units 40 includes a stationary first portion 50 with a second portion 54 movably positioned within the first portion 50 in a biased manner. When burning in electronic devices 18 without an integrated heat sink that are deeply recessed within the sockets 14 of a burn-in board 12, the fluid pressure to the second portion 54 is preferably increased thereby extending the second portion 54 from the first portion 50 thereby reducing the effective distance from the surface of the electronic device 18.

The invention described herein relates to a stand-alone burn-in system. In other words, the thermal management system, the burn-in boards and chips, and the control system are all packaged into a stand-alone piece of equipment. However, it can be appreciated that the present invention may be embodied in an alternative form that can be described as having a central pump/control station that services multiple satellite burn-in stations serviced by a central reservoir 80, as well as a common fluid distribution system. In addition, the present invention is suitable for other spray cooling applications such as thermal management of one or more electronic devices.

1 ***B. Spray Enclosure***

2 Figures 4 through 6 illustrate an exemplary spray enclosure **20** having an interior
3 cavity **22** for receiving at least one burn-in board **12**. The spray enclosure **20** may be
4 comprised of any structure capable of housing a burn-in board which are commonly
5 utilized within the burn-in industry or other unit not utilized within the burn-in industry.
6 The spray enclosure **20** preferably has an opening and a door for selectively closing and
7 sealing the opening as is conventional with spray enclosures **20** utilized within the burn-in
8 industry. The spray enclosure **20** preferably has a rail structure **16** or other structure for
9 receiving and supporting one or more burn-in boards **12** in a desired position with respect
10 to the corresponding spray assembly **30**. It can be appreciated that the spray units **30** and
11 the burn-in boards **12** may be stacked within the interior cavity **22** of the spray enclosure **20**
12 depending upon the total number of burn-in boards **12** to be utilized simultaneously. The
13 present invention may also be configured to receive a self-contained rack unit containing a
14 plurality of arrays of spray assemblies **30** for allowing quick changing of the electronic
15 devices thereby increasing the operational time of the burn-in system.

16
17 It can be appreciated that the spray enclosure **20** may have various structures and
18 configurations not illustrated within Figures 4 through 6 of the drawings that may be
19 suitable for usage with the present invention. U.S. Patent No. 5,880,592 provides an
20 exemplary burn-in spray enclosure **20**.

21
22 As shown in Figures 4 and 5 of the drawings, an inlet tube **24** extends into the spray
23 enclosure **20** for providing the fluid to the spray assembly **30** as will be discussed in further
24 detail. As further shown in Figures 4 and 5 of the drawings, an outlet tube **26** extends from
25 the spray enclosure **20** returning the fluid recovered from the spray enclosure **20** to the
26 reservoir **80**.

27
28 United States Patent No. 6,108,201 entitled Fluid Control Apparatus and Method
29 for Spray Cooling to Tilton et al. also describes the usage of spray technology to cool a

1 printed circuit board. Spray thermal management may be performed locally (i.e. where the
2 chip is sprayed directly), globally (i.e. where the chip and surrounding electronics/boards
3 are also sprayed), a combination of locally and globally, or in conjunction with air cooling
4 or other cooling methods. In a spray thermal management system, most if not all of the
5 spray components are contained within the spray chassis such as but not limited to the
6 spray unit, the card cage, valves, pumps, filters, separators and the like.

8 *C. Burn-In Board*

9 The present invention may utilize various structures and types of burn-in boards
10 12 that are commonly utilized within the burn-in industry. The burn-in board 12
11 includes one or more sockets 14 arranged in a desired pattern as shown in Figure 9 of
12 the drawings. Each of the sockets 14 removably receives, through an opening, an
13 electronic device 18 to be tested during the burn-in phase. The fluid is sprayed from
14 the spray nozzles through this opening to engage a surface of the electronic device 18
15 contained within the sockets 14 for maintaining the desired temperature of the
16 electronic devices 18 within.

17
18 The sockets 14 are electrically connectable to the electronic device 18 inserted
19 within the respective sockets 14. The burn-in board 12 is then electrically coupled to a
20 control unit 60 via a communications port or other structure attached to the burn-in
21 board 12 that controls the test signals sent to each of the electronic devices 18 during
22 the burn-in testing procedure. U.S. Patent Nos. 6,404,219, 6,181,146 and 5,825,171
23 illustrate exemplary burn-in devices and burn-in systems which are suitable for usage
24 with the present invention. It can be appreciated that various other burn-in board 12
25 structures and configurations may be utilized with the present invention.

26
27 In addition, a temperature sensor 62 may be attached to each of the sockets 14,
28 directly upon the electronic devices 18 for measuring the temperature of the electronic
29 devices 18 during testing, or may come embedded directly within the chips. Devices

1 for measuring the temperature of electronic devices 18 are commonly utilized within
2 the burn-in industry that may be utilized with the present invention. Examples of
3 suitable temperature sensors 62 include but are not limited to thermocouple,
4 thermopile, electronic devices capable of inferring temperature of the electronic device
5 18 from the electronic device's power draw, or infrared devices.

6 7 *D. Spray Assembly*

8 The spray assembly 30 has a housing containing of one or more spray units 40
9 as illustrated in Figures 7 and 8 of the drawings. The spray assembly 30 preferably is
10 comprised of a relatively flat structure, however various other structures may be
11 utilized to construct the spray assembly 30.

12
13 Each of the spray units 40 is arranged upon the spray assembly 30
14 corresponding to a specific socket 14 within the burn-in board 12. There may or may
15 not be a pattern for the plurality of spray units 40 such as but not limited to a row
16 pattern as illustrated in Figures 6 and 7, or a staggered pattern.

17
18 Each of the spray units 40 includes a housing structure 42 having an interior
19 housing cavity 43 covered by a rear plate 44 as shown in Figures 10 through 17 of the
20 drawings. The rear plate 44 may be attached to the housing structure 42 using various
21 fastening devices. The housing structure 42 may have various sizes and shapes other
22 than illustrated in the drawings. A first port 45 and a second port 46 are fluidly
23 connected within the housing structure 42 which fluidly correspond to the first portion
24 50 and the second portion 54 of the spray units 40 respectively.

25
26 As shown in Figures 10 through 17 of the drawings and for the present
27 embodiment of the invention, each of the spray units 40 has a first portion 50 and a
28 second portion 54 movably positioned within the first portion 50, though a simpler
29 non-movable nozzle structure may also be utilized with the present invention. Figures

1 10 and 11 illustrate the usage of a circular structure with a partially enclosed upper
2 end. However, the first portion **50** may have various shapes and structures for
3 dispensing the fluid onto the electronic device **18**.

4
5 The first portion **50** entirely or partially surrounds the second portion **54** as best
6 illustrated in Figure 10 of the drawings. One or more first orifices **52** extend within
7 the first portion **50** in various patterns. The first orifices **52** may have various
8 characteristics, shapes, sizes, styles, designs, arrangements and densities. The first
9 orifices **52** may be arranged to provide various spray patterns amongst multiple
10 orifices, or various cone angles from each individual orifice, upon the electronic
11 device **18**. Cone angles may be of the full cone variety as is known in the art, or of the
12 hollow cone variety as is also known in the art, and may vary from 10° to 60°, but are
13 not limited to varieties, or this angular range. It is desirable to utilize first orifices **52**
14 that provide an adjustable spray pattern depending upon the heat flux of the electronic
15 device **18** being tested. The first orifices **52** dispense the pressurized fluid from within
16 the housing cavity **43** as shown in Figure 16 of the drawings.

17
18 As shown in Figure 11 of the drawings, a main opening **48** extends into the first
19 portion **50**. The main opening **48** has a shape and size similar to the second portion **54**
20 such as but not limited to circular, square, oval, rectangular and the like. The main
21 opening **48** is sufficient in size to allow for the sliding movement of the second portion
22 **54** within the main opening **48**.

23
24 As shown in Figures 14, 16 and 17 of the drawings, a tubular portion **53**
25 extends downwardly from an interior surface of the upper end of the first portion **50**.
26 The tubular portion **53** preferably surrounds the main opening **48** within the first
27 portion **50** and extends downwardly a finite distance for slidably receiving the second
28 portion **54**. A channel **55** fluidly extends from the second port **46** to the tubular
29 portion **53** in a sealed manner to provide pressurized fluid to the second portion **54**

1 independently of the first portion 50 as best illustrated in Figure 13 of the drawings. It
2 can be appreciated that a single channel may feed both the first portion 50 and the
3 second portion 54.
4

5 As shown in Figure 11 of the drawings, the second portion 54 is comprised of a
6 tubular structure with one or more second orifices 56 within the upper end thereof.
7 The second orifices 56 may have various characteristics, shapes, sizes, styles, designs,
8 arrangements, patterns and densities. The second portion 54 is formed to slidably
9 extend within the main opening 48 and the tubular portion 53 as best illustrated in
10 Figures 16 and 17 of the drawings. At least one seal member 58 is positioned within
11 the second portion 54 for sealing the second portion 54 within the tubular portion 53 as
12 best illustrated in Figure 11 of the drawings. A longitudinal cutout 51 preferably
13 extends into the lower end of the first portion 50 which movably fits about the channel
14 55 thereby allowing entry of the fluid from the channel 55 into the second portion 54.
15

16 For a given cone type (full cone or hollow), each of the first orifices 52 and
17 second orifices 56 may have static spray cone angles or dynamic spray cone angles.
18 Dynamic spray cone angles may be utilized dependent upon changing thermal
19 management requirements for the electronic device 18. For example, if it is desirable
20 to reduce the cooling of the electronic device 18, one or more of the orifices 52, 56
21 may be adjusted to reduce the surface area that is sprayed with the fluid by adjusting
22 the spray cone angles in response to temperature feedback. Conversely, if it is
23 desirable to increase the cooling of the electronic device 18, one or more of the orifices
24 52, 56 may be adjusted to increase the surface area that is sprayed with the fluid by
25 adjusting the spray cone angles in response to temperature feedback.
26

27 The second portion 54 is downwardly biased within the tubular portion 53 by a
28 biasing device which may be comprised of various biasing structures such as but not
29 limited to springs 57. The biasing device is preferably comprised of one or more

1 springs 57 attached between the tubular portion 53 and the second portion 54 as
2 illustrated in Figures 16 and 17 of the drawings. One or more support members 59 are
3 attached to a lower end of the tubular portion 53 and within the second portion 54
4 wherein the springs 57 are connected between thereof.

5
6 When the fluid pressure within the channel 55 and the second portion 54 is
7 increased sufficiently to overcome the biasing force of the springs 57, the second
8 portion 54 is then extended outwardly from the first portion 50 as illustrated in Figure
9 17 of the drawings. A lower flanged portion extending from the second portion 54
10 preferably engages a lip within the tubular portion 53 thereby preventing the second
11 portion 54 from overextending from within the first portion 50.

12
13 When the fluid pressure within the channel 55 and the second portion 54 is not
14 sufficient to overcome the biasing force of the springs 57, the second portion 54 is then
15 retained downwardly within the first portion 50 with the upper ends of the first portion
16 50 and the second portion 54 substantially level to one another as illustrated in Figure
17 16 of the drawings. It can be appreciated that varying fluid pressure within the channel
18 55 and the second portion 54 will extend the second portion 54 at varying distances.

19
20 The spray assembly 30 preferably includes a first inlet port 34 that is fluidly
21 connected to the first portion 50 of the spray units 40 and a second inlet port 36 that is
22 fluidly connected to the second portion 54 of the spray units 40. A first valve 84
23 preferably controls the fluid flow from the inlet tube 24 to the first inlet port 34. The
24 first port 45 within the spray units 40 receives the fluid flow from the first inlet port 34
25 thereby providing the pressurized fluid to the housing cavity 43 of the spray units 40
26 for dispensing from the first portion 50 of the spray units 40.

27
28 A second valve 86 preferably controls the fluid flow from the inlet tube 24 to
29 the second inlet port 36. The second port 46 within the spray units 40 receives the

1 fluid flow from the second inlet port 36 for dispensing through the second orifices 56
2 within the second portion 54.

4 *E. Dynamic Spray Control*

5 Figure 18 of the drawings illustrates an exemplary dynamic spray control for
6 the spray units 40. The dynamic spray control may be used for one or more of the
7 orifices 52, 56. As shown in Figure 18, a chamber 31 is provided that is fluidly
8 connected to the first orifice 52. One or more feed ports 32 are fluidly connected to
9 the chamber 31 for providing a cross fluid flow into the chamber 31 with respect to the
10 direction of spray from the first orifice 52. A center jet 35 extends within an inlet
11 plate 33 partially surrounding the chamber 31 opposite of the first orifice 52. The inlet
12 plate 33 may have various thickness, however it is preferably to maintain the thickness
13 of the inlet plate 33 between 0.005 – 0.20 inches. A thicker inlet place 33 provides
14 increased control over the fluid flow.

16 A plunger 37 is positioned within the center jet 35 that has a tapered end
17 portion as illustrated in Figure 18 of the drawings. The plunger 37 controls the amount
18 of fluid that flows through the center jet 35. As the fluid flows into the chamber from
19 the center jet 35, the fluid is combined with fluid flowing into the chamber
20 transversely from one or more feed ports 32 creating a swirling effect within the
21 chamber 31. As the plunger 37 is retracted from the center jet 35, an increased flow
22 rate of the fluid is provided to the chamber 31 thereby reducing the amount of swirling
23 of the fluid within the chamber 31 that occurs because of the feed port 32. The center
24 jet 35 and the plunger 37 may be sized such that when the plunger 37 is fully retracted
25 from the center jet 35, a relatively straight jet of fluid passes through the first orifice
26 52 instead of an atomized spray.

28 Various technologies may be utilized to control the position of the plunger 37
29 within the center jet 35 such as but not limited to digital stepper motors, linear

1 actuators, magnetostrictive actuators or mechanical devices. In addition, each plunger
2 37 may be controlled individually or in a group by using a common mechanical or
3 electrical structure by the control unit 60. The plunger 37 may be positioned within the
4 feed port 32. In addition, the inlet plate 33 may be moved with respect to the plunger 37 in
5 a stationary position to create a similar effect. A piezo-crystal or magnetostrictive material
6 positioned between the inlet plate 33 and the walls of the chamber 31 may be utilized to
7 manipulate the position of the inlet plate 33. Various other devices may be utilized to
8 control the flow of fluid into the chamber 31 and thereby control the characteristics of the
9 fluid spray dispersed from the first orifice 52.

11 *F. Fluid Distribution System*

12 The reservoir 80 is comprised of a container structure capable of retaining a
13 desired volume of fluid. The reservoir 80 may have various shapes, sizes and
14 structures which are commonly utilized to construct a reservoir 80. The fluid utilized
15 within the present invention is preferably comprised of a dielectric fluid such as but
16 not limited to hydrofluoroether (HFE). However, the fluid utilized may be comprised
17 of a non-dielectric such as but not limited to water.

19 The reservoir 80 may include a thermal conditioning unit 90 for increasing or
20 decreasing the temperature of the fluid within the reservoir 80 to a desired temperature
21 to be sprayed upon the electronic devices 18 during the burn-in process. The thermal
22 conditioning unit 90 may be comprised of a combination heater unit and cooling unit.
23 A heat exchanger may be utilized to increase the temperature of the fluid within the
24 reservoir 80 by exchanging the heat from the fluid returning from the spray enclosure
25 20 after spraying upon the electronic devices 18. An inline heater/cooler may also be
26 utilized to thermally condition the fluid prior to or after spraying from the nozzles.

28 A main pump 82 is fluidly connected to the reservoir 80 for drawing the dielectric
29 fluid from within the reservoir 80. The fluid pressure within the fluid distribution system

1 may be maintained by operation of the main pump 82 and/or a return valve 85 which
2 allows for the return of fluid to the reservoir 80 to lower the fluid pressure as shown in
3 Figure 1 of the drawings. Various other pressure regulating devices may be utilized to
4 control the fluid pressure on the pressurized side of the pump. The main pump 82 is
5 fluidly connected to the first valve 84 and the second valve 86 as further illustrated in
6 Figure 1 of the drawings thereby providing pressurized fluid to the spray units 40 at the
7 desired pressure.

8
9 As shown in Figure 1 of the drawings, a fluid collector 28 is positioned within the
10 spray enclosure 20 for collecting the fluid after being sprayed upon the electronic devices
11 18. The fluid collector 28 may be comprised of various collecting devices such as but not
12 limited to a pan structure. The fluid collector 28 is fluidly connected to the reservoir 80 for
13 returning the used fluid to the reservoir 80. A filter device may be positioned within the
14 fluid collector 28 or the reservoir 80 for filtering the fluid after being sprayed upon the
15 electronic devices 18 for removing undesirable particulate materials and chemicals which
16 might interfere with the operation of the spray units 40.

17
18 A vapor recovery unit 70 may be fluidly connected to or within the spray enclosure
19 20 for collecting and condensing fluid that has undergone a phase change to vapor. The
20 vapor recovery unit 70 may be comprised of condensing coils and similar other devices
21 capable of condensing vapor. The vapor recovery unit 70 may be utilized during and after
22 the burn-in process.

23 24 ***G. Control Unit***

25 The control unit 60 may be comprised of various electronic devices capable of
26 communicating with and controlling the burn-in board 12, the thermal conditioning
27 unit 90, the main pump 82, the first valve 84, the second valve 86, the return valve 85
28 and the vapor recovery unit 70. The control unit 60 may be comprised of a computer
29 or other electronic device capable of receiving and storing commands.

1
2 The control unit **60** may communicate with the external electrical devices such
3 as but not limited to electrically or via communications signal. The control unit **60**
4 may be programmed to operate the external devices at various operating levels such as
5 but not limited to controlling the temperature of the fluid within the reservoir **80**,
6 controlling the fluid pressure and flow rate emitted by the main pump **82**, controlling
7 the spray pattern and flow of the orifices **52**, **56**, and controlling the flow of fluid to the
8 spray unit **40**. It can be appreciated that more than one control unit **60** may be utilized
9 to control one or more of the components of the present invention.

10 11 *H. Operation*

12 In use, the electronic devices **18** are properly positioned within the sockets **14**
13 of the burn-board **12**. The burn-in board **12** is then positioned within the spray
14 enclosure **20** with the surface of the electronic devices **18** facing substantially
15 downwardly toward the upper end of the corresponding spray units **40**. The dielectric
16 fluid within the reservoir **80** is heated to a desired temperature for cooling or heating
17 the electronic devices **18** with or without using a conditioning unit **90**. The main pump
18 **82** and valves **84**, **86** may be utilized to achieve and maintain the target junction
19 temperature even though the fluid temperature may not be the desired temperature.
20 The main pump **82** is operated to provide the pressurized fluid to the spray assembly
21 **30**.

22
23 If the electronic devices **18** being burned in have a relatively high profile (e.g.
24 electronic devices **18** with integrated heat sinks which have a lower heat flux thereby
25 requiring less fluid flow for cooling purposes), then both the first valve **84** and the
26 second valve **86** are opened to provide fluid to the first portion **50** and the second
27 portion **54** at a substantially constant pressure. As further shown in Figure 16 of the
28 drawings, fluid is sprayed from both the first orifices **52** and the second orifices **56**
29 without the second portion **54** elevated with respect to the first portion **50**.

1
2 If the electronic devices **18** being burned-in have a low profile within the socket
3 as illustrated in Figure 17 of the drawings (e.g. electronic devices **18** without
4 integrated heat sinks which have a higher heat flux thereby requiring increased fluid
5 flow for cooling purposes), then the first valve **84** is closed and the second valve **86** is
6 opened with increased fluid pressure being supplied to the second portion **54** thereby
7 extending the second portion **54** upwardly from the first portion **50** near the electronic
8 device **18**.

9
10 It is desirable to decrease the spraying distance between the distal end of the
11 second portion **54** and the surface of the electronic device **18** when high heat flux
12 conditions exist requiring additional cooling. Conversely, it is desirable to increase
13 the spraying distance between the distal end of the second portion **54** and the surface
14 of the electronic device **18** when low heat flux conditions exist requiring less cooling.

15
16 As the fluid or fluid is sprayed upon the electronic device **18**, the control unit
17 **60** applies the desired voltage to the electronic devices **18** for burn-in testing purposes
18 thereby increasing or lowering the temperature of the electronic device **18**. If the
19 device temperature of the electronic device **18** rises above a desired temperature (e.g.
20 100° Celsius), then the flow rate X of the fluid is increased to the spray units **40** as
21 shown in Figure 3 of the drawings. In addition to or independent of increasing the
22 flow rate X, the spray pattern size emitted from one or more of the orifices **52**, **56** may
23 be increased to engage an increased surface of the electronic device **18** of the
24 electronic device thereby increasing the cooling of the electronic device **18**. Instead of
25 increasing the size of the spray pattern for increasing the cooling of the electronic
26 device, the spray pattern may also be directed to and focused upon a specific area of
27 the electronic device **18** that has a high heat flux compared to other areas of the
28 electronic device **18**.

1 If the device temperature of the electronic device **18** is lowered below a desired
2 temperature, then the flow rate X of the fluid is decreased to the spray units **40** as
3 shown in Figure 3 of the drawings. In addition to or independent of decreasing the
4 flow rate X , the spray pattern size emitted from one or more of the orifices **52**, **56** may
5 be decreased to engage an reduced surface of the electronic device **18** thereby reducing
6 the cooling of the electronic device **18**. Instead of decreasing the size of the spray
7 pattern for decreasing the cooling of the electronic device, the spray pattern may also
8 be directed away from a specific area of the electronic device **18** that has a high heat
9 flux compared to other areas of the electronic device **18**. In addition, the spray pattern
10 may be increased in size thereby reducing the spray engaging high heat flux areas of
11 the electronic device **18**.

12
13 If the device temperature of the electronic device **18** is approximately equal to a
14 desired temperature, then the flow rate X of the fluid is maintained to the spray units
15 **40** as shown in Figure 3 of the drawings. In addition, the spray pattern size is
16 preferably maintained relatively constant for each of the orifices **52**, **56** where the
17 device temperature of the electronic device **18** is approximately equal to the desired
18 temperature.

19
20 In order to control the device temperature of the electronic device **18**, the power
21 level may also be increased or lowered independently or in conjunction with the
22 control of the fluid flow rate. The AC and DC power levels may be adjusted to
23 manipulate the electronic device's temperature.

24
25 Various methods of thermal management may be employed for the electronic
26 devices **18**. For adequately low heat fluxes, it may be appropriate to cool the electronic
27 devices **18** through purely forced convection (i.e. no effective evaporation of the coolant
28 occurs). For intermediate heat fluxes, it may be appropriate to utilize a combination of
29 forced convection and phase change heat transfer (i.e. the latter method resulting in

1 evaporation of the coolant). For the highest level of heat fluxes, it may be appropriate to
2 optimize purely on phase change heat transfer. For optimization on an approach that is
3 dominated by phase change, it is critical to have a system design and method of operation
4 that allows the maintenance of a thin coolant film on the electronic devices at all times.
5 Upon coolant delivery to the electronic devices 18, all coolant is returned to the reservoir
6 80 for reuse. In situations where vapor is generated, the system is designed such that the
7 pressure generated by the vapor assists in the return of the vapor and any condensed or
8 unevaporated coolant back to the reservoir 80.

9
10 As the fluid is sprayed upon the electronic devices 18, the fluid engaging the
11 electronic devices 18 may be partially vaporized. The vapor is eventually condensed
12 as the temperature of the vapor is reduced after shutdown. The vapor may also be
13 condensed by pressure increases within the spray enclosure 20 or via the vapor
14 recovery unit 70 during or after operation of the present invention. The non-vaporized
15 fluid passes downwardly within the spray enclosure 20 to the fluid collector 28 where
16 the fluid is then filtered and returned to the reservoir 80 for reuse.

17
18 This process continues until the electronic devices 18 are fully burned-in over
19 the required amount of time. Once the burn-in process is completed, the flow of the
20 fluid is terminated. All vapor is recovered during the fluid recovery phase, and
21 unevaporated coolant on the burn-in board 12, sockets and other, is made to evaporate
22 for subsequent recovery. The burn-in board 12 and electronic devices 18 are then
23 removed from the spray enclosure 20 for replacement with other burn-in boards 12 and
24 electronic devices 18.

25
26 What has been described and illustrated herein is a preferred embodiment of the
27 invention along with some of its variations. The terms, descriptions and figures used
28 herein are set forth by way of illustration only and are not meant as limitations. Those
29 skilled in the art will recognize that many variations are possible within the spirit and

1 scope of the invention, which is intended to be defined by the following claims (and
2 their equivalents) in which all terms are meant in their broadest reasonable sense
3 unless otherwise indicated. Any headings utilized within the description are for
4 convenience only and have no legal or limiting effect.